ASC

Astro Sciences Center

21 p.

Report No. P-1

THE SCIENTIFIC OBJECTIVES OF DEEP SPACE INVESTIGATIONS

JUPITER

Title THE SCIENTIFIC OBJECTIVES OF DEEP SPACE INVESTIGATIONS:

(NASA CR-53735;

Report No. P-1;

(Formerly part of Rep~~ort No~~t. 1. 4P2 No. 2, ← do not index last report #
Sep~~tember~~ 1963) OTS: $2.60 ph, $0.83 mf

JUPITER

by

p.a. → D. L. Roberts
Astro Sciences Center
of
c.a. → IIT RESEARCH INST~~ITUTE~~
Chicago, Ill~~inois~~ 1252352

CP

for

Lunar and Planetary Programs
National Aeronautics and Space Administration
Washington, D. C.

(NASA Contract ~~No.~~ NASr-65(06))

APPROVED:

L. Reiffel

L. Reiffel, Director

Mar~~ch~~ 9 1964 21p refs

ACKNOWLEDGEMENT

The author gratefully acknowledges the contributions, comments and criticisms of the staff of Astro Sciences Center, IIT Research Institute.

ABSTRACT

JUPITER

19567 A-

This document reports the first in a series of studies being undertaken by ASC/IITRI on the Scientific Objectives of Deep Space Investigations. The theories of origin of Jupiter are discussed and are followed by a summary of the physical properties of Jupiter.

The measurements which are proposed are (1) spectrometry and polarimetry of the Jovian atmosphere and if possible the surface, (2) photography of the complex atmospheric appearance of Jupiter including observations through holes in the cloud cover either at the poles or over the Red Spot, (3) magnetic field measurements throughout the mission and in the supposedly high intensity field of Jupiter which may extend to 1 AU from the surface, (4) temperature measurement using microwave techniques to measure temperatures under the cloud layer, (5) detection of plasma and particles in space and in the proposed intense radiation belts, and (6) measurement of interplanetary dust and in particular any dust cloud associated with Jupiter. At a later stage, biological measurements should be considered in and below the atmosphere.

In the general discussion of missions to Jupiter it is assumed that it will be possible to traverse the asteroid belt without incident. A fly-by of Jupiter at 10 planetary radii will provide much data which will be useful. However an orbiting space probe or even one which lands on a satellite of

Jupiter and is thus always pointing toward the planet are of sufficient interest, particularly in the period of time over which they will be able to collect data, for consideration even as a first mission as the state of the art progresses. Entry into the atmosphere of Jupiter and possibly landing on the planet are probably in the second phase of investigation but will then open up the fields of meteorology, seismology and biology. An essential part of the early missions to Jupiter will be to gather data on interplanetary space between the Earth and Jupiter.

TABLE OF CONTENTS

		Page No.
1.	INTRODUCTION	1
2.	THE ORIGIN OF JUPITER	1
3.	PHYSICAL PROPERTIES OF JUPITER	3
	3.1 Mass and Density	3
	3.2 Size	3
	3.3 Brightness	3
	3.4 Albedo and Color	4
	3.5 The Red Spot	4
	3.6 Temperature	5
	3.7 Atmosphere	5
	3.8 Surface	6
	3.9 Structure and Composition	6
	3.10 Magnetic Field	7
	3.11 Trapped Radiation Belts	7
	3.12 Micrometeorites and Dust	8
4.	BASIC SCIENTIFIC QUESTIONS	8
5.	BASIC MEASUREMENTS	9
	5.1 Spectrometry and Polarimetry	9
	5.2 Photography and TV	10
	5.3 Magnetic Fields	10
	5.4 Radiometry	10
	5.5 Radiation Detection	10
	5.6 Dust and Micrometeorite Detection	11
	5.7 Biology	11

TABLE OF CONTENTS (Cont'd)

		Page No.
6.	IMPORTANCE OF JOVIAN DATA	11
7.	JOVIAN MISSIONS	11
REFERENCES		13

JUPITER

1. INTRODUCTION

Jupiter is the largest known planet in the solar system having a diameter of 1/10th that of the Sun. It orbits the Sun at a mean distance of 5.2 AU with a period of approximately 12 years; the orbit has a small eccentricity of 0.048 and an inclination to the ecliptic of only 1° 18'. It has a dense atmosphere with a heavy and characteristic cloud layer which prohibit observation of its surface, but which give the appearance of light and dark belts moving rapidly across the planet. The most well known feature of Jupiter is the red spot which has not been satisfactorily explained. Jupiter characterizes the Jovian group of planets which are large and have low densities compared with the terrestrial planets which are small and have high densities. Jupiter is surrounded by twelve satellites.

2. THE ORIGIN OF JUPITER

A number of theories have been postulated for the origin of the planets and the solar system, but there are two basic mechanisms which embrace most of these, one hydrodynamic and the other magnetohydrodynamic.

Kuiper (1951, 1956) has extended the theories of Kant, Laplace, Roche and Weisacker and assumes the solar system has condensed from a massive stellar cloud with only mechanical forces and dynamics involved.

Rabe (1956, 1958) has been able to show the stability of the system with essentially the same orbital parameters as exist today. The planets are formed from very large protoplanets which reduce their size by evaporation. Jupiter is assumed to have reduced by a factor of 20 to its present size (Kuiper 1956). The satellites of planets are allowed to form as localized condensations within the protoplanet system and are released as satellites during the shrinking process. Urey (1952, 1956) although accepting the basic theory would object to the inclusion of the terrestrial planets in just one single condensation of the solar system and would suggest the process occurred at least twice. For the particular case of Jupiter it has been proposed that the planet could not be formed from a gas cloud but would require solid grains, probably hydrogen, which snowed out at a temperature of about 4°K, and that helium was acquired later in the process (Opik 1962).

The other basic theory of origin has been extended by Alfven (Alfven 1954, Alfven and Wilcox 1962) from the earlier hypotheses of Birkeland, Berlage and Dauville. This theory again postulates condensation from a stellar cloud but requires the gas to be hot and ionized so that the fall inwards towards the Sun is stopped by the solar magnetic field at distances from the Sun determined by the magnitude of the field and the type of ions condensing. In order to support this theory Alfven supposes the solar magnetic field to be considerably larger than it appears to be at present. He is then able to postulate that the terrestrial planets were formed from a different cloud than the giant planets and further that the satellites were formed by the same mechanism but with the individual planets now as the center of attraction.

Both the above theories although agreeing on a condensation and coagulation of matter from a stellar cloud, differ radically in the mechanism. Neither can be proved or disproved and both have many aspects in their favor.

3. PHYSICAL PROPERTIES OF JUPITER

Jupiter has been observed in varying degrees of detail for some 300 years and although only the atmosphere and cloud layer can actually be observed, many deductions have been made on its physical properties.

3.1 Mass and Density

Jupiter is by far the most massive planet having some 318 times the mass of the Earth. The density is low by Earth standards being 1.3 g/cc which is approximately the same as the density of the Sun.

3.2 Size

The enormous planet has about 1/10 th of the diameter of the Sun being almost 140, 000 km across the equator. However it is oblate to 1 part in 15.

3.3 Brightness

The brightness of Jupiter exceeds a magnitude of -2.5 (at opposition) although accurate photometric data for Jupiter are quite limited (Sagan 1963). The mean opposition magnitudes for Jupiter have been found to vary with an amplitude of 0.34 mag in a period of 11.6 ± 0.4 years. With regard to the variation of brightness with solar phase angle a small value for the phase coefficient of the order of 0.005 mag/deg seems probable.

3.4 Albedo and Color

Jupiter has a measured albedo of 0.44 which compares with the minimum for a planet of 0.15 for Mars and the maximum of 0.75 for Venus.

Many colors have been seen including greys, browns, reds and blues, and must be associated with the atmosphere and cloud layer which forms the visible surface. All the colors are pale and despite chromatic effects arising in the Earth's atmosphere and in optical systems (Peek 1958) the various colors are agreed to be real. The reasons for the colors are not known but Wildt (1939) has suggested sodium in ammonia as an explanation particularly since sodium has been found in the Earth's upper atmosphere. Urey (1958) suggests many of the possible compounds of carbon, nitrogen and hydrogen are responsible but Kiess (1960) favors oxides of nitrogen as the cause.

3.5 The Red Spot

The Red Spot of Jupiter is the well known colored region which has varied between a brick red and a barely discernable grey over the 130 years it has been observed. It is about 40,000 km long and some 13,000 km wide and although almost stable in latitude it shows considerable motion in longitude. Its motion has led to explanations as a floating raft on a liquid or highly compressed gas but it has always been difficult to explain why it should not have moved to a position of minimum gravity on the equator. Hide (1963) suggests it may be a discontinuity 2-3 km high on the surface of Jupiter providing the crust of Jupiter has a non-uniform motion. The prevention of cloud formation over the spot is then explained by Taylor columns generated by the height of the surface, and the color has been associated with organic compounds. The Red Spot is no longer considered to be the source of the bursts of radio emission from Jupiter (Smith and Carr 1961).

3.6 Temperature

Temperature measurements have been made with both infrared and microwave radiometers, but the position of the temperature sources are not known precisely. The temperature of 130°K usually quoted for Jupiter is an infrared measurement through the Earth's atmospheric window (8-14μ) and since an ammonia band occupies most of this window, the temperature must be considered to be that of ammonia in the upper Jovian atmosphere. The temperatures determined at microwave frequencies should more nearly represent the surface temperature but have been found to vary between 170°K for 3 cm wavelengths up to 70,000°K at 70 cm wavelengths. The longer wavelength radiation is clearly non-thermal and there is a suggestion that the shorter wavelength data also contains a non-thermal component.

3.7 Atmosphere

Ammonia and methane having bands in the visible spectrum were the first atmospheric constituents to be discovered but are not the major ones. Hydrogen was first deduced from occultation and later by measurement of its quadrupole rotation - vibration spectrum by Herzberg (1949) in the laboratory and by Kiess (1960) for Jupiter itself. The composition of the Jovian atmosphere has been deduced as containing mainly hydrogen with lesser quantities of helium and neon and with ammonia, methane and argon as impurities.

The most striking features of the atmosphere of Jupiter are the light and dark cloud belts which move at velocities up to 10^4 cm/sec and indicate severe turbulence and atmospheric activity. However the manifestation of atmospheric activity is similar over the whole planet, which shows a prevailing eastward motion, is stronger in the Southern hemisphere, and has an apparent cycle of 20-22 years (Focas 1963).

3.8 Surface

The nature of the Jovian liquid or solid surface is completely unknown since it is not visible from the Earth. However the greenhouse effect of methane and ammonia will contribute to higher surface temperatures which Sagan has suggested may even approach the temperatures on the Earth. Thus a possibly warm surface, a reducing atmosphere, and a primordial abundance of oxygen could produce a situation similar to the one which existed on the Earth when life forms were established. Sagan (1963) has noted that simple organic molecules are produced in high yield by electric discharges which could be considered within the atmospheric activity of Jupiter. The eventual search for life and pre-life forms on Jupiter will be an exciting phase of solar system exploration.

3.9 Structure and Composition

The most generally accepted theory for the constitution of Jupiter is one of a solid metallic hydrogen core (Opik 1962). However Jupiter, with its low density could still have an Earth mass of iron and silicates within its core. The model proposed by De Marcus (1958) assumes 78% H and 22% He with the helium increasing monotonically towards the center. In order to make the model agree with the observed gravitational and inertial properties of Jupiter, a dense core is assumed at the center, some 12,000 km dia and ten times the mass of the Earth. In the model, which follows the work of Stewart (1956) on the composition of solidified gases, the transition from solid hydrogen to metallic hydrogen occurs at about 1/5 of the radius in from the surface.

3.10 Magnetic Field

The existence of a Jovian magnetic field is implied in the interpretation of radio emission from the planet. The cyclotron theory of radio emission from radiation belts would require a surface field of 10^3 gauss while a synchrotron theory reduces the required field by an order of magnitude (Field 1960, Davis 1961). There are also indications that the magnetic field axis is quite asymmetric with respect to the geographical axis. (Warwick 1958). The explanation of the magnetic field in terms of a dynamo theory is not valid if indeed Jupiter has a metallic hydrogen core and the only reasonable suggestion which avoids this problem is that the field is primordial and has decayed very little over the last few billion years.

3.11 Trapped Radiation Belts

The existence of trapped radiation belts is implied by the large magnetic fields that were postulated to explain the radio emission. Several models have been proposed to describe these radiation belts, based on an analysis of observed emission (Warwick 1958, Chang and Davis 1962). It is suggested that two trapped radiation belts exist, one centered at 1.5 radii and the other between 2 and 3 radii. These belts are pictured as being asymmetrical to the planet's geographical axis as a result of an asymmetric dipole moment. This distance is consistent with the fact that radio emission is observed at a distance of 3 radii from the planet. Calculations based on radio emission suggest that there are at least 10^2 particles/cm^3 greater than in the Earth's radiation belts, and that a different energy distribution exists (Chang and Davis 1962). A satisfactory explanation has not yet been found for the energy source which maintains the large radiation belts unless a very high energy conversion mechanism exists for the radio emission.

3.12 Micrometeorites and Dust

No data exists for the dust distribution in the vicinity of Jupiter. However it is known from meteor studies that in the Earth's vicinity impacts occur at a rate of about 7 per hour and appear to vary inversely with distance from the Earth to a 1.4 power law (Whipple 1961). Results from Mariner II indicate that the region between Earth and Venus has a density some 10^4 times lower than near the Earth. It would be useful to compare the near Earth and near Jupiter dust environments to see if some relationship exists which will indicate a source of the dust and a retention mechanism.

4. BASIC SCIENTIFIC QUESTIONS

The number of scientific questions which can be asked about Jupiter exceed, by far, the vast number of questions which still remain unanswered on the Earth itself. However some of the more immediate questions which are pertinent to our understanding of Jupiter are given below.

4.1 What is the construction and constitution of the core and surface layers of Jupiter?

4.2 Can the age of Jupiter be determined?

4.3 What is the constitution and pressure of the atmosphere?

4.4 Can the coloration of Jupiter be explained?

4.5 What is the nature of the Red Spot?

4.6 What is the temperature distribution and energy balance throughout the atmosphere and bulk of Jupiter?

4.7 Is there an internal source of heat in Jupiter?

4.8 What is the topography of the Jovian surface?

4.9 What is the magnitude and configuration of the magnetic field?

4.10 What is the distribution and size and energy balance of the radiation belts around Jupiter? and do auroral phenomena exist?

4.11 What is the mass distribution and constitution of meteoroids in the vicinity of Jupiter?

4.12 Is there evidence of life or pre-life forms on Jupiter or in the Jovian atmosphere?

5. BASIC MEASUREMENTS

A vast number of measurements will eventually be made on Jupiter and in its environment. The following suggestions are made as the basis of an extending series of experiments which will lead to an understanding and explanation not only of Jupiter but the whole solar system.

5.1 Spectrometry and Polarimetry

The Jovian atmosphere, cloud cover and possibly the surface in the polar regions should be examined to yield information concerning the constituents, pressure and temperature of the atmosphere. Measurements from the far infrared to the far ultraviolet are indicated but just a few spectral regions will be adequate initially to extend Earth or near Earth measurements, and to help in the interpretation of the colors of Jupiter.

5.2 Photography and TV

Pictures of Jupiter, with its complex atmospheric appearance, will be most revealing if obtained from a probe in its near vicinity. Much higher resolution pictures than are obtainable from Earth taken over a period of at least a few hours will give much information on the activity of the atmosphere. A region of particular interest will be the Red Spot which is assumed not to be covered by clouds. Some information on the atmospheric strata may be obtained by observing any holes in the cloud layer particularly in the region of the Red Spot or the poles.

5.3 Magnetic Fields

Very useful experiments could be performed by measuring the magnetic fields in the whole region between Earth and the surface of Jupiter. The very large Jovian field should be easy to monitor but it is probable that its complexity will not be fully determined in just one or two missions.

5.4 Radiometry

Temperature measurements for the surface of the planet would seem possible using microwave detection and this should be extended to cover the whole surface before attempts should be made to penetrate the atmosphere with a space probe. Further measurements should be made on the non-thermal radio emission from the planet if possible, through and inside the radiation belts.

5.5 Radiation Detection

The radiation belts of Jupiter should be probed to determine their nature and to compare them with the Earth's belts in view of the vastly different magnetic fields, their different position regarding solar radiation, and their energy balance.

5.6 Dust and Micrometeorite Detection

Measurements of interplanetary dust should be made between Earth and Jupiter and in particular evidence should be obtained on the distribution and constitution of any particulate matter near the Jovian atmosphere.

5.7 Biology

Initial biological evidence may be obtained by collecting and analyzing samples of the atmosphere particularly in the region of the Red Spot. At a later stage, detailed examination of the lower atmosphere and surface should be seriously considered.

6. IMPORTANCE OF JOVIAN DATA

Further investigation of Jupiter cannot help but increase our understanding of the solar system. The many deductions and hypotheses that have been applied to the planet deserve verifying or disproving and this will only be possible with missions from Earth to Jupiter. Jupiter is of added interest since it is the nearest planet of an apparently separate group from the Earth and has yielded, even from Earth observations, a tantalizing wealth of data already. It is a large object in a predictable orbit and therefore presents a relatively amenable target for the near future.

7. JOVIAN MISSIONS

Due to its position relative to the Earth, a mission to Jupiter must be considered as one of the early deep space missions. The major unknown factor in sending a spacecraft to Jupiter is how difficult will it be to traverse the asteroid belt. This problem may be solved by probing the belt first with fairly simple probes or it may be possible to envisage a non-ecliptic trajectory which goes around the asteroids. On the assumption that this difficulty can be overcome there is a great deal of scientific reward in approaching even to within ten planetary radii (i. e. 7×10^5 km) of Jupiter. However there is no doubt that an orbiting probe, or Jovian moon lander will give much more data than a flyby and this should be considered even as a first mission as the state of the art progresses. The very dense atmosphere of Jupiter precludes early penetration of the cloud layer with a probe although this is probably a necessity before the ultimate goal of landing on Jupiter can be achieved, and the whole field of meteorological, seismic, and biological experiments can be performed. However not only measurements on Jupiter itself are possible on a Jovian mission but important data can be obtained on the interplanetary space between the Earth and Jupiter, on the asteroid belt and perhaps on the satellites of Jupiter.

REFERENCES

Alfven, H. (1954) On the Origin of the Solar System, Oxford University Press

Alfven and Wilcox (1962), Astrophys. J. 3, 136

Chang and Davis (1962) Astrophys. J. 136 567

Davis and Chang (1961) J. Geophysical Research 66 2524

De Marcus, W. C. (1958) Astronomical J. 63, 2

Field, G. B. (1959) J. Geophysical Research 64, 1169,

Field, G. B. (1960) J. Geophysical Research 65, 1661

Focas, J. H. (1963) Memoirs Soc. Roy des Science de Liege 5, VII

Herzberg, G. (1949) Nature 163, 170

Hide, R. (1963) Memoirs Soc. Roy des Science de Liege 5, VII

Kiess, C. C. et al (1960) Astrophys. J. 132, 221

Kuiper, G. P. (1951) Origin of the Solar System, Astrophysics (Edited by Hynek) McGraw Hill Book Company

Kuiper, G. P. (1956) Formation of the Planets, J. Roy. Astron. Soc. Can.

Kuiper and Middlehurst (1961) Planets and Satellites

Opik, E. J. (1962) Icarus Vol. 1, 200

Peek, B. M. (1958) The Planet Jupiter, Faber and Faber

Rabe, E. (1956) Origin of Kirkwood Gaps, Astrophys. J. 40, 107

Rabe, E. (1958) Astronomical J. 63, 407

REFERENCES (Cont'd)

Sagan, C. (1963) Memoirs Soc. Roy des Science de Liege 5, VII

Smith and Carr (1961) Quarterly J. of Florida Academy of Science 24, 185

Stewart, J. W. (1956) Physics and Chemistry of Solids 1, 146

Urey, H. C. (1952) The Planets, Yale University Press

Urey, H. C. (1956) Diamonds, Meteorites and the Origin of the Solar System, Astrophys. J. 124, 623

Urey, H. C. (1958) Atmospheres of the Planets, Handbuch der Physik, Vol. 52

Warwick, J. W. (1958) Astronomical J. 63, 2

Wildt, R. (1939) Monthly Notices of Roy. Astron. Soc. 99, 616

Whipple, F. L. (1961) Particulate Contents of Space, Columbia University Press